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GAMMA-RAY ABSORPTION FOR A BEAM MODEL OF THE CRAB NEBULA PULSAR NP0532

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(NASA-GSFC Preprint X-641-71-468)

Page 3, equation (5) should read

$$\lambda_\gamma = [N_x \sigma (1 - \cos \theta)]^{-1} \propto \epsilon^\beta R_e^{2}$$

Page 4,

equations for lower limits on E_c should read (in order)

$$E_c \geq 15.6 \text{ GeV } (R_e/R_p)$$

and

$$E_c \geq 12.5 \text{ GeV } (R_e/R_p)^{2/3}$$

Page 4, last line should read

"tion will occur below 10 GeV ... "

Hopefully, these errors will be corrected prior to publication in the January 3,1972 issue of Nature Physical Science.

We wish to thank Prof. Kenneth Greisen for bringing this error to our attention.

γ-Ray Absorption for a Beam Model of the Crab Nebula Pulsar NP0532

by

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The possibility of γ-ray absorption in the vicinity of the crab nebula pulsar NP0532 was pointed out by McBreen[1]. Recently Pollack, et al.[2] have shown that the critical energy E_c above which absorption is observed to take place can, in principle, be used to determine the size of the emitting region in γ-ray sources such as pulsars, quasars and supernovae explosions. However, neither of these papers attempted to take account of beaming in pulsars such as NP0532 which has the effect of significantly raising the value of E_c. Without taking account of beaming, there would appear to be a conflict between surface emission models such as that of Chiu, et al[3]. and recent reports of the detection of pulsed γ-ray emission from the Crab Nebula[4-6]. These observations would appear to rule out any model involving emission from the surface of the pulsar according to the calculations of Pollack, et al. since those calculations indicate that γ-radiation originating at the surface of the pulsar with energies greater than 1 MeV would be strongly attenuated.

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We present here what we feel to be a more plausible model for estimating γ-ray absorption from NP0532 by estimating the effect of beaming as indicated by the pulsations themselves rather than by assuming γ-ray absorption by interaction with an isotropic photon field as was assumed by McBreen and by Pollack, et al.

The main absorption process to consider is that of pair production in the intense photon field as was assumed by McBreen and by Pollack, et al.

The main absorption process to consider is that of pair production in the intense photon field which occurs during the pulse, i.e., in the beam, the interaction being of the form

$$\gamma + \gamma \rightarrow e^{+} + e^{-} \tag{1}$$

We assume, as did McBreen, that the volume occupied by the lower energy photons (in this case hard X-ray photons) is larger than that in which the γ-rays originate. The thresh-hold energy for (1) is $2mc^2$ in the cms of the interaction which implies $\varepsilon_x E_\gamma\,(1-\cos\theta) \geq 2(mc^2)^2$ for the interaction to take place, where ε_x is the energy of the hard x-ray photon causing the interaction. The cross section for (1) has a peak value of $\simeq 0.7\sigma_0$ at $\varepsilon_x E_\gamma\,(1-\cos\theta) \approx 2\ (\text{MeV})^2$ where $\sigma_0 = \pi(e^2/mc^2)^2 = 2.5 \times 10^{-25}\ \text{cm}^2$. We will assume a mean value of $\sigma \simeq \sigma_0/2$ for $1.5\ (\text{MeV})^2 \leq \varepsilon_x E_\gamma (1-\cos\theta) \leq 3\ (\text{MeV})^2$ with all energies to be given in MeV. With the further assumption that the spectrum $n(\varepsilon_x)$ of pulsed X-rays decreases steeply with energy, it follows that the critical [illegible] is given by

$$E_c \approx \frac{1.5\ (\mathrm{MeV})^2}{\varepsilon_x\ (1-\cos\ \theta)} \qquad (2)$$

The photon density of pulsed hard X-rays is given by

$$N_x(\ \varepsilon_x) = n_x(\varepsilon_x)\Delta\varepsilon_x \simeq 4J_0(\varepsilon_x)c^{-1}(D/R_e)^2 \qquad (3)$$

where $J_0(\ \varepsilon_x)$ is the average flux observed at the earth and is taken to be of the form $J_0(\varepsilon_x) = K\varepsilon_x^{-\beta}$, D is the distance to the pulsar, taken to be 1.7 kpc (see reference 7) and R_e is the radius of the γ-emitting region.

Thus,

$$N_x(\varepsilon_x, R_e) \propto R_e^{-2}\ \varepsilon_x^{-\ \beta} \qquad (4)$$

and the mean free path for absorption of γ-rays has the dependence

$$\lambda_\gamma = [N_x\sigma(1-\ \cos\theta)]^{-1} \propto \varepsilon_x^{\beta}R_e^2 \qquad (5)$$

Thus, at the critical energy for absorption $\lambda/R_e = 1$ $\propto \varepsilon_x^{\beta}R_e$ and therefore by assuming a constant average value of $(1-\cos\theta)$, it follows from (2)

$$E_c \propto \varepsilon_x^{-1} \propto R_e^{1/\beta} \qquad (6)$$

We will now estimate a value for $(1-\cos\theta)$ based on the observations of the pulse width of pulsed emissions from NP0532 as a fraction of the total period. We will consider here only the pulsed γ-emission as this is the only component of γ-radiation which we can presently hope to observe from NP0532. Defining $(\Gamma/2)$ as the half width at half maximum of the pulse interval, the half-angle

for emission, θ_e, is then taken to be $\pi\Gamma T^{-1}$ where T is the total period of the pulsar. Assuming that $\theta_{e,x} \geq \theta_{e,\gamma}$, the half-angle for interaction (1) on the average is then given approximately by $\theta \leq 2^{1/2}\theta_{e,x}$ Taking the observed value for $\Gamma/2$ of 0.5 ms (see references 8-10), we then find that $\theta \simeq 0.13$ rad and therefore $(1-\cos\theta) \simeq 8 \times 10^{-3}$.

We will use two different expressions for $J_0(\varepsilon_x)$ as given in the literature:

A) $J_0(\varepsilon_x) = 3.5 \times 10^{-3}\varepsilon_x^{-1}$ (Hillier, et al.[11])

B) $J_0(\varepsilon_x) = 5.3 \times 10^{-4}\varepsilon_x^{-1.5}$ (Kurfess[8]; see also Orwig, et al.[10])

For $J_0(\varepsilon_x)$ as given by Hillier, et al.,

$$N_x = 1.2 \times 10^{19}\varepsilon_x^{-1}(R_e/R_p)^{-2},$$

where R_p is the radius of the pulsar, taken to be 10km, and

$$E_c \geq 15.6 \text{ GeV } (R_e/R_p)$$

On the other hand, using the value for $J_0(\varepsilon_x)$ given by Kurfess[8], we find

$$E_c \geq 12.5 \text{ GeV } (R_e/R_p)^{2/3} .$$

Adding to this the uncertainty in the distance D and the fact that $N_x(\varepsilon_x) \propto D^2$ as well as the possibility that the beaming could be narrower than the value we have used, it becomes questionable whether we can conclude that strong absorption will occur in the pulsed γ-ray component for any of the source models proposed for NP0532. Our results indicate that for the model presented here one cannot conclude that absorption will occur below 10 GeV even if the γ-radiation is em-

itted at the surface of the pulsar. This conclusion contradicts the result of Pollack, et al. who concluded that for surface emission, absorption would occur at and above 1 MeV.

We would like to thank Professor Kenneth Greisen for pointing out an important omission in the original draft of this paper.

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